Supplementary information

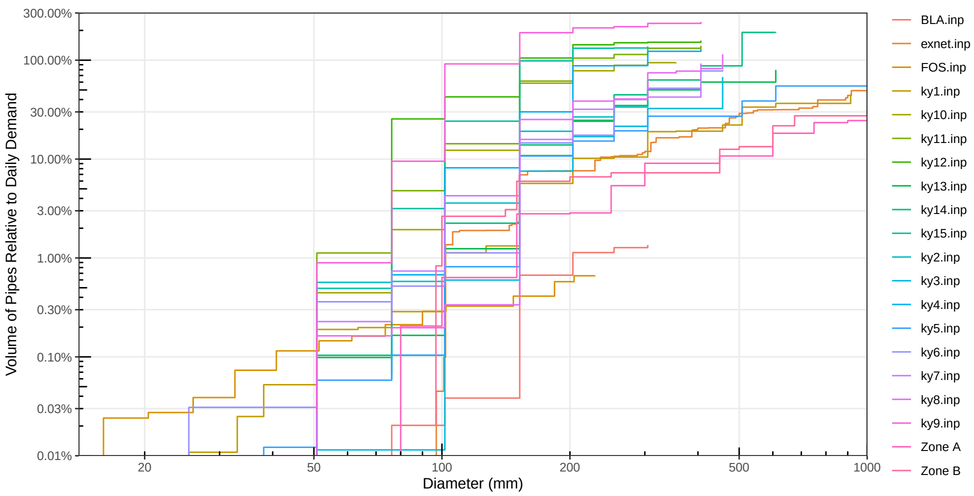

Fig. S1: The volume of air (normalized by daily water demand) that must be displaced during filling depends on cumulative volume of pipes in the network. 18 reference networks and two confidential intermittent networks.

S1 Pump and valve characteristics

Pressures and flows measured during the tests allowed the estimation of the valve and pump characteristic curves.

The differences between the pressures at transducers P_P and P_U provided the head drop upstream and downstream of the butterfly valve UV. The measured pressure head differences and discharges are represented by diamonds in Figure S2. The nonlinear fitting of the data yielded the expression

$$\Delta H = 0.01111Q^2 \tag{S1}$$

with Q measured in liters per second and ΔH in meters.

The measured pressures at transducers P_P and discharges at flow meter FM are also represented by circles in the same figure. The nonlinear fitting of the data yielded the expression of teh characteristic curve of teh pumping system PS

$$\Delta H = 20.57 - 0.2063\, Q^{1.393} \tag{S2}$$

with Q measured in liters per second and ΔH in meters.

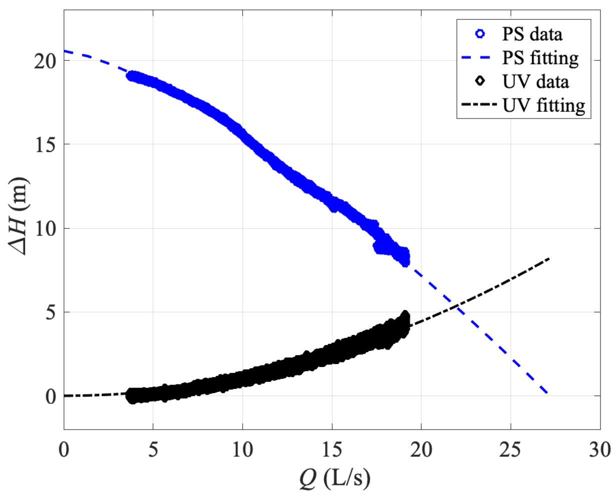

Fig. S2: The characteristic curves of the pumping system PS (dashed line) and upstream valve UV (dash-dotted line) are estimated by the fitting the experimental data (circles and diamonds).

S2 Modeled vs. measured discharges

To refine our understanding of measured and modeled air discharge, both are compared directly using the three tests of SJ meter in Figure S3. Since the water meter impeller starts rotating at a mean air discharge rate of 3.65 L/s (5.26 Q_3 in Figure 4) data do not lay on the plane bisector (dotted line crossing the origin). The data are also not parallel with this bisector, suggesting that the metered discharges are not simply offset by this activation flow rate (traingles). Although a positive correlation between measured and modeled data is clear, any attempt to interpret the result by a complete model in the given space is simplistic. Amidst this complexity, we focus on the simplest useful model; linear regression.

If the x-intercept and the slope are both estimated (dashed line), the predicted relationship is $Q_{\text{meter}} = 1.05\,(Q_{\text{model}} - 2.42Q_3)$. While this model underestimates the activation flow rate, its suggests a nearly one-to-one relationship between measured and modeled air flow, once the intercept is offset. The accuracy of this model is particularly low before the true activation flow is reached (5.26 Q_3). If instead, the intercept is fixed at 5.26 Q_3, the best fit model is $Q_{\text{meter}} = 1.40\,(Q_{\text{model}} - 5.26Q_3)$. This model suggests that measured water meter flow rates increase 40% faster than air flow rates after adjusting for the activation discharge. Both regression models are highly influenced by the larger flows, and are less accurate in the range of smaller flows, particularly for the case of the single 1/4-inch valve (blue line).

Given the unknowns in intermittent supply and the many assumptions in our regression model, we suggest a simplified interpretation of the regression results: $Q_{\text{meter}} \approx Q_{\text{model}} - 2.42Q_3$. While the water meters did not begin to register flow until 5.26 Q_3, the approximate ratio of measured flow rate to (modeled) air flow rate can be approximated as modeled air flow rate less 1.68 L/s (2.42 Q_3).

S3 Effects of the air density

The relationship between air-registration in the water meters and air density (and pressure) is explored in Figure S4. In this figure, the water-meter-registered volumetric flow of air leaving the filling pipe (Q_{WM}) is normalized by the flow-meter-registered volumetric flow of water entering the system (Q). For a given system setup, this measurement fraction increases throughout the experiment as the pipe fills and as air

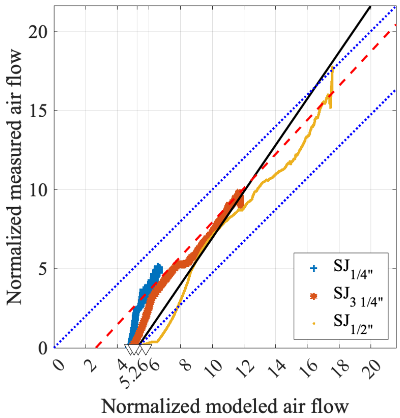

Fig. S3: Modeled air discharge rate (Q_a) versus the discharge measured by the single-jet water meter (Q_{WM}; circles) for the tests with the SJ water meter. Data are normalized by Q_3. The linear fitting of the data with a given intercept (solid line) is also shown. Bisectors (dotted lines) are plotted for reference.

density . But comparing across system setups, there is no clear relationship between density and measured flow fraction.

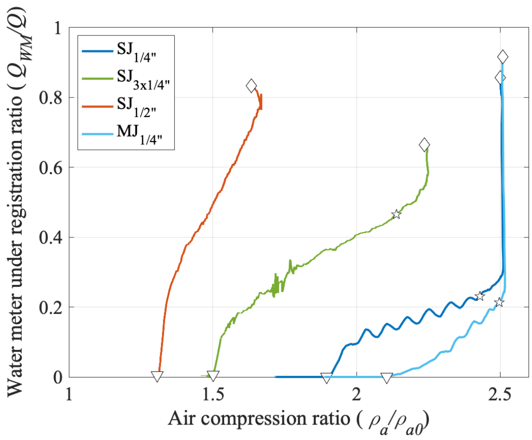

Fig. S4: Variation with the dimensionless air density ($\rho'_a = \rho_a/\rho_{ao}$) compared to the ratio between the discharge measured by water meter, Q_{WM}, and flowmeter, Q. The initial air density ρ_{ao} =1.20 kg/m^3 is used as a reference. Markers denote the start of the water meter measurements (triangles), the achievement of the choked flow conditions through the valve (stars), and the arrival of the water front at the downstream end of the pipe (diamonds).

Air compression is related to the filling speed of the pipe and the downstream resistance - both of which also affect the degree of over-registration. Air compression reduces the volume of discharged air when compared to an imagined scenario of the same discharge rates without compression. But Figure S4 suggests that there is no direct and simple relationship between air pressure (density) and over-registration. As an example, in the test with the smallest downstream valve (1/4"), the air density increases up to 2.5 times with respect to the initial normal condition (ρ_{ao} = 1.2 kg/m^3) as a consequence of the high pressures reached by air. Nevertheless, the ratio of the discharge measured by the water meter in this condition is close to that ratio measured with the largest downstream valve diameter (1/2"), despite the different densities (pressures).

S4 Water meter effects on boundary conditions

The effects of water meters on filling and air dynamics were assessed by comparing tests with the same valve configuration with and without the SJ water meter installed. The presence of the water meter slowed filling (measured at FM) negligibly when one 1/4" valve is open downstream of the water meter, but meaningfully when three 1/4" valves or a 1/2" valve are installed Figure S5). The effect of water meter friction was evident in the filling tests we ran, particularly when the pipes filled faster (larger downstream orifice area).

Once the pipe was filled, the water meter was subject to an almost constant pressure head across all valve conditions (range: 20.4 to 20.7 m)). While the manufacturer of the SJ water meter reports a loss coefficient of 13.46 m s^2 L^{-2}, our measured loss coefficients (during steady water flow) changed with downstream valve conditions; k_{WM} =44.70, 31.90 and 16.20 m s^2 L^{-2} with one 1/4", three 1/4" and one 1/2" open downstream ball valves, respectively.

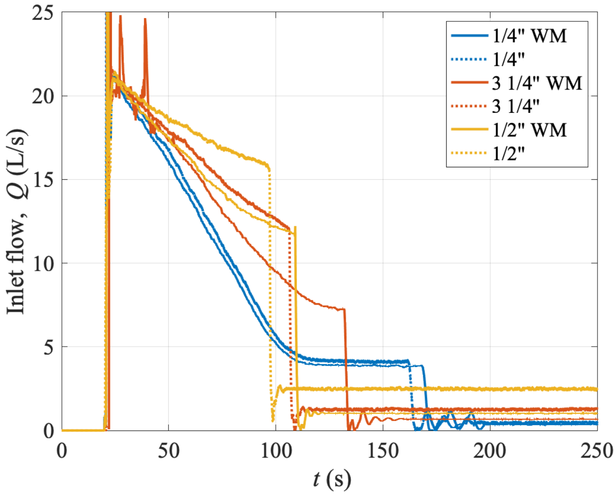

Fig. S5: Inlet flow measured at FM during tests with the single-jet water meter of Figure (WM, solid lines) and without it (dotted lines) with 1/4", 3 1/4" and 1/2" ball valves at the pipe downstream end.